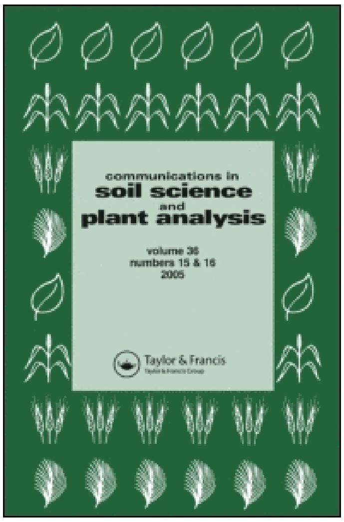

Communications in Soil Science and Plant Analysis
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597241

Modeling Effect of Residual Nitrogen on Response of Corn to Applied Nitrogen

W. R. Reck [a]; A. R. Overman [b]
[a] U.S. Department, Agriculture Natural Resources Conservation Service, Gainesville, Florida, USA [b] Agricultural and Biological Engineering Department, University of Florida, Gainesville, Florida, USA

Online Publication Date: 01 June 2006

To cite this Article Reck, W. R. and Overman, A. R.(2006)'Modeling Effect of Residual Nitrogen on Response of Corn to Applied Nitrogen',Communications in Soil Science and Plant Analysis,37:11,1651 — 1662

To link to this Article: DOI: 10.1080/00103620600710298

URL: http://dx.doi.org/10.1080/00103620600710298

Communications in Soil Science and Plant Analysis, 37: 1651–1662, 2006

ISSN 0010-3624 print/1532-2416 online
DOI: 10.1080/00103620600710298

Modeling Effect of Residual Nitrogen on Response of Corn to Applied Nitrogen

W. R. Reck
U.S. Department of Agriculture Natural Resources Conservation Service, Gainesville, Florida, USA

A. R. Overman
Agricultural and Biological Engineering Department, University of Florida, Gainesville, Florida, USA

Abstract: The logistic model has been used extensively to describe crop response to applied nutrients and water availability. It contains three parameters that can be estimated from data by regression analysis. One of the parameters refers to the reference state of the system, either at zero applied nitrogen (N) or applied N to reach 50% of maximum yield ($N_{1/2}$). A negative value of $N_{1/2}$ indicates that the soil already contains more than enough N to reach 50% of maximum yield. In the present analysis, data from a field study at Watkinsville, Georgia, which measured response of corn [*Zea mays* (L.) Pers.] to applied N following plowunder of grass sod is used to verify this point. It was found that $N_{1/2}$ shifted from $-50\,\mathrm{kg\,ha^{-1}}$ in the first year to $+25\,\mathrm{kg\,ha^{-1}}$ after several years. Availability of N from decaying vegetation declined exponentially with time. The time constant for decomposition and nitrification was 2 years. Total amount of N released from the vegetation was estimated as $190\,\mathrm{kg\,ha^{-1}}$.

Keywords: Corn, model, nitrogen

Received 27 August 2004, Accepted 25 July 2005
Address correspondence to A. R. Overman, Agricultural and Biological Engineering Department, University of Florida, Gainesville, FL l32611, USA. E-mail: aroverman@ifas.ufl.edu

INTRODUCTION

Corn production depends on level of applied nutrients and water availability. The logistic model has been used to describe forage grass response to applied nitrogen (Overman, Martin, and Wilkinson 1990). It was later used to analyze response of corn to applied nitrogen and water availability from rainfall (Reck and Overman 1996). The model has been extended to describe plant uptake of nitrogen as well as biomass production (Overman, Wilkinson, and Wilson 1994; Overman, Wilson, and Kamprath 1994). A rational basis has been provided for the model (Overman 1995), and it has been compared to quadratic and Mitscherlich models (Overman and Scholtz 2003).

In this article, the logistic model is used to evaluate the effect of residual nitrogen released when grass sod was turned under on response of corn to applied nitrogen.

MODEL DESCRIPTION

The logistic model for yield response to applied nitrogen is given by Overman, Martin, and Wilkinson (1990):

$$Y = \frac{A}{1 + \exp(b - cN)} \tag{1}$$

where N = applied nitrogen, kg ha^{-1}; Y = crop yield (dry matter), Mg ha^{-1}; A = maximum crop yield at high N, Mg ha^{-1}; b = intercept parameter; and c = nitrogen response coefficient, ha kg^{-1}. Note that the units of c are the inverse of units on N. The logistic model contains the three parameters A, b, and c. Two of these (b and c) occur in nonlinear form. Parameters are estimated by nonlinear regression. Characteristics of the logistic model have been discussed in detail by Overman (1995). Parameters A and c are positive, whereas parameter b can be positive, zero, or negative.

It is sometimes convenient to write Eq. (1) in the equivalent form

$$Y = \frac{A}{1 + \exp[(N_{1/2} - N)/N']} \tag{2}$$

where characteristic N (N') and applied N to reach 50% of maximum yield ($N_{1/2}$) are defined by

$$N' = \frac{1}{c} \tag{3}$$

$$N_{1/2} = \frac{b}{c} = bN' \tag{4}$$

It follows that parameter N' is positive, whereas parameter $N_{1/2}$ can be positive, zero, or negative. A negative value of $N_{1/2}$ indicates that the soil already contains more than enough nitrogen to reach 50% of maximum yield.

DATA ANALYSIS

Data for this analysis are taken from a study at the USDA Southern Piedmont Conservation Research Center at Watkinsville, Georgia (Carreker et al. 1977) on response of corn to applied nitrogen. The soil was Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult). Plots were laid out on a field, which had been in grass sod for 3 years, either Kentucky 31 fescue [*Festuca arundinacea* Schreb.] or Coastal bermudagrass [*Cynodon dactylon* (L.) Pers.]. Sod was turned under and the response of Dixie 82 corn to applied nitrogen was measured 1, 2, 3, and 4 years after sod was turned under. Plant population was 25,000 plants ha^{-1}. The experiment was designed to measure availability of nitrogen from decaying grass residue. Grain yields were corrected to 15% moisture content; yields are reported here as dry matter. Data for 1967 are used in this analysis when rainfall in June and July totaled 35.3 cm.

Experimental results are listed in Table 1 for corn on fescue sod and in Table 2 for corn on bermudagrass sod. Data are plotted in Figures 1 and 2. Our goal is to estimate parameters for the logistic model for these data. Because parameters b and c occur in the model in nonlinear form, nonlinear regression is used to estimate all three parameters (Adby and Dempster 1974). Three different modes of analysis are included. In mode 1, it is assumed that common values of parameters A, b, and c apply to data for all

Table 1. Yield response of corn grain (Y) to applied nitrogen (N) following three years of fescue at Watkinsville, Georgia (1967)[a]

N (kg ha^{-1})	Years after fescue	Y (Mg ha^{-1})
0	1	7.76
	2	6.81
	3	4.64
	4	3.63
45	1	9.40
	2	8.57
	3	7.34
	4	6.84
90	1	9.20
	2	9.32
	3	9.19
	4	9.28
180	1	8.97
	2	8.73
	3	9.03
	4	9.19

Note: [a]Data from Carreker et al. (1977).

Table 2. Yield response of corn grain (Y) to applied nitrogen (N) following three years of bermudagrass at Watkinsville, Georgia (1967)[a]

N (kg ha^{-1})	Years after bermudagrass	Y (Mg ha^{-1})
0	1	8.54
	2	5.68
	3	4.42
	4	4.27
45	1	8.56
	2	8.67
	3	7.56
	4	7.72
90	1	9.19
	2	9.16
	3	9.21
	4	9.54
180	1	9.11
	2	8.94
	3	9.06
	4	8.86

Note: [a]Data from Carreker et al. (1977).

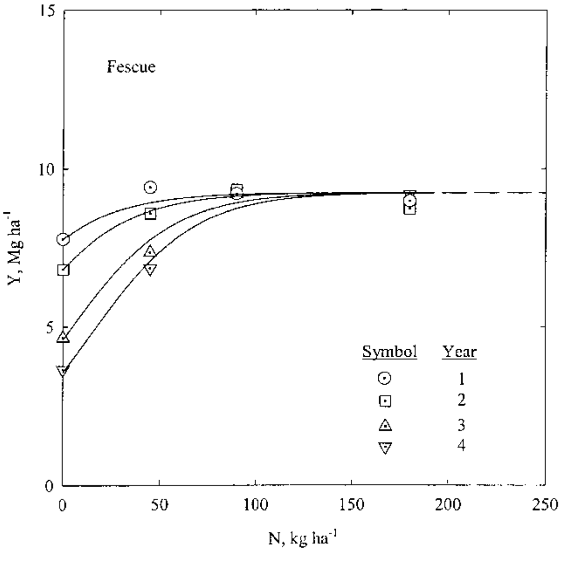

Figure 1. Response of corn to applied nitrogen after three years of fescue sod at Watkinsville, Georgia (1967). Data from Carreker et al. (1977). Curves drawn from Eq. (1) with parameters from Table 3.

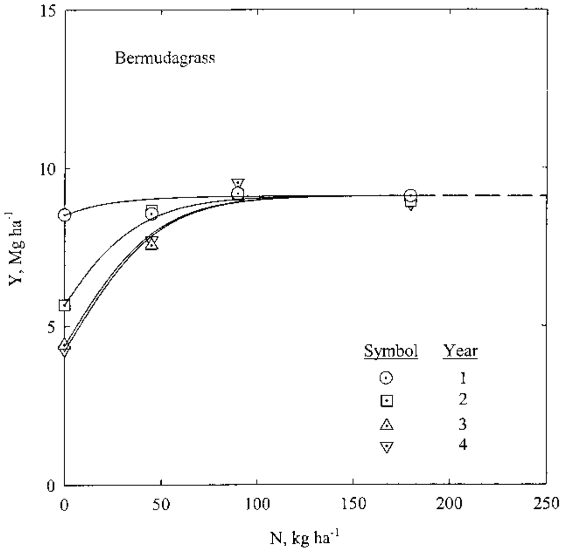

Figure 2. Response of corn to applied nitrogen after three years of bermudagrass sod at Watkinsville, Georgia (1967). Data from Carreker et al. (1977). Curves drawn from Eq. (1) with parameters from Table 4.

4 years. In mode 2, data for each year are analyzed separately. In mode 3, common A and c with individual b are assumed. These results are given in Table 3 for fescue and Table 4 for bermudagrass. Values of the nonlinear correlation coefficient R are listed as well. Because mode 2 provides the best fit of the model to the data, it is used as the standard of comparison. Negative values of parameter b signify that more than enough nitrogen was present in the soil to reach 50% of maximum grain yield.

Analysis of variance (ANOVA) is used to evaluate the different modes of parameter estimation. Degrees of freedom (df) is equal to the number of observations (16) minus the number of parameters estimated (which varies by mode). The residual sum of squares (RSS) is calculated from the definition

$$RSS = \sum_{i=1}^{16} \left(Y_i - \hat{Y}_i\right)^2 \tag{5}$$

where Y_i = measured yield for the ith observation, Mg ha^{-1}, and $\hat{Y}_i$ = estimated yield for the ith observation, Mg ha^{-1}. Mean sum of squares (MSS) is then calculated from MSS = RSS/df. Results are listed in Table 5 for fescue and Table 6 for bermudagrass. Because the variance ratio (F) exceeds the critical value of F(9, 4, 95) = 6.01 for both grasses, it is concluded that mode 2 is significantly better than mode 1 at the 95% confidence level; at least one of the model parameters must vary among years.

Table 3. Model parameter estimates for corn following three years of fescue at Watkinsville, Georgia (1967)

Mode	Year	A ($Mg\,ha^{-1}$)	b ($ha\,kg^{-1}$)	c ($ha\,kg^{-1}$)	R ($ha\,kg^{-1}$)
(1) Common *A*, *b*, *c*	All	9.17	−0.49	0.036	0.8132
(2) Individual *A*, *b*, *c*	1	9.19	−1.69	0.78	0.9711
	2	9.01	−1.13	0.047	0.9693
	3	9.26	0.02	0.034	0.9914
	4	9.46	0.52	0.036	0.9929
(3) Common *A*, *c*	All	9.24		0.037	0.9863
Individual *b*	1		−1.66		
	2		−1.03		
	3		0.02		
	4		0.48		

On the other hand, because F for mode 3 is far below the critical value of F(6, 4, 95) = 6.16, it is concluded that all variation among years can be accounted for by variation in parameter *b*. The curves in Figures 1 and 2 are drawn from Eq. (1) with parameters listed in Tables 3 and 4 for mode 3.

A summary of model parameters is given in Table 7. The question naturally occurs as to commonality of parameters *A*, *b*, and *c* for fescue and bermudagrass sod. Analysis of variance for comparison of these two cases is given in Table 8. In mode 1, separate values of the parameters are assumed, which leads to MSS = 0.114. In mode 2, average values listed in Table 7 are used with MSS = 0.260. This results in a variance ratio of F = 2.29, which is slightly less than the critical value F(6, 20, 95) = 2.60. Mode 2 can be accepted on a marginal basis.

Table 4. Model parameter estimates for corn following three years of bermudagrass at Watkinsville, Georgia (1967)

Mode	Year	A ($Mg\,ha^{-1}$)	b ($ha\,kg^{-1}$)	c ($ha\,kg^{-1}$)	R ($ha\,kg^{-1}$)
(1) Common *A*, *b*, *c*	all	9.18	−0.49	0.037	0.8345
(2) Individual *A*, *b*, *c*	1	9.30	−2.34	0.011	0.8470
	2	9.05	−0.52	0.059	0.9981
	3	9.25	0.11	0.038	0.9955
	4	9.23	0.17	0.043	0.9864
(3) Common *A*, *c*	all	9.12		0.044	0.9881
Individual *b*	1		−2.69		
	2		−0.50		
	3		0.08		
	4		0.15		

Table 5. Analysis of variance of model parameters for corn following three years of fescue at Watkinsville, Georgia

Mode	Parameters	df	RSS	MSS	F
(1) Common *A*, *b*, *c*	3	13	15.62	1.20	—
(2) Individual *A*, *b*, *c*	12	4	0.84	0.21	—
(1) −(2)	—	9	14.78	1.64	7.85
(3) Common *A*, *c* Individual *b*	6	10	1.25	0.13	—
(3) −(2)	—	6	0.41	0.068	0.33

Note: F(9, 4, 95) = 6.01; F(6, 4, 95) = 6.16.

Dependence of $N_{1/2}$ on year is shown in Figure 3. We assume that this parameter is converging toward 25 kg ha^{-1}. The curve is drawn from

$$N_{1/2} = 25 - 75\exp[-0.50(T-1)] \tag{6}$$

where $T =$ year after sod is turned under: 1, 2, 3, 4, ... The curve in Figure 3 is drawn from Eq. (6) for visual purposes only.

These results are now placed into quantitative perspective. The total amount of nitrogen released from the sod and made available for uptake by corn for the first year appears to be approximately $25 + 50 = 75$ kg ha^{-1} (Figure 3). From results for the first year the logistic model can be written as

$$Y = \frac{A}{1 + \exp[(N_{1/2} - N)/N']} = \frac{9.18}{1 + \exp[-50 - N/25]} \tag{7}$$

Table 6. Analysis of variance of model parameters for corn following three years of bermudagrass at Watkinsville, Georgia

Mode	Parameters	df	RSS	MSS	F
(1) Common *A*, *b*, *c*	3	13	13.36	1.03	—
(2) Individual *A*, *b*, *c*	12	4	0.72	0.18	—
(1) – (2)	—	9	12.64	1.40	7.78
(3) Common *A*, *c* Individual *b*	6	10	1.04	0.10	—
(3) – (2)	—	6	0.32	0.053	0.29

Note: F(9, 4, 95) = 6.01; F(6, 4, 95) = 6.16.

Table 7. Summary of model parameters for corn following grass sod at Watkinsville, Georgia

Grass	Year	A (Mg ha^{-1})	b (ha kg^{-1})	c (ha kg^{-1})	N′ (kg ha^{-1})	$N_{1/2}$ (kg ha^{-1})
Fescue	All	9.24		0.037	27	
	1		−1.66			−45
	2		−1.03			−28
	3		0.02			1
	4		0.48			13
Bermuda	All	9.12		0.044	23	
	1		−2.69			−61
	2		−0.50			−11
	3		0.08			2
	4		0.15			3
Avg.	All	9.18		0.040	25	
	1		−2.18			−53
	2		−0.76			−20
	3		0.05			2
	4		0.32			8

Because parameters A and N' remain constant with time, the model can be written for the limiting case as

$$Y^* = \frac{A}{1 + \exp[(N^*_{1/2} - N^*)/N']} = \frac{9.18}{1 + \exp[(+25 - N^*)/25]} \qquad (8)$$

where N^* = applied N under limiting conditions, kg ha^{-1}, and N* = applied N to reach 50% of maximum yield under limiting conditions, kg ha^{-1}. Response curves are shown in Figure 4 (for year 1) and Figure 5 (for limiting case). In other words, Eqs. (7) and (8) represent the same equation

Table 8. Analysis of variance of model parameters comparing corn following three years of fescue or bermudagrass at Watkinsville, Georgia

Mode	Parameters	df	RSS	MSS	F
(1) Individual A, b, c	12	20	2.27	0.114	—
(2) Common A, b, c	6	26	3.83	0.147	—
(2) − (1)	—	6	1.56	0.260	2.29

Note: F(6, 20, 95) = 2.60.

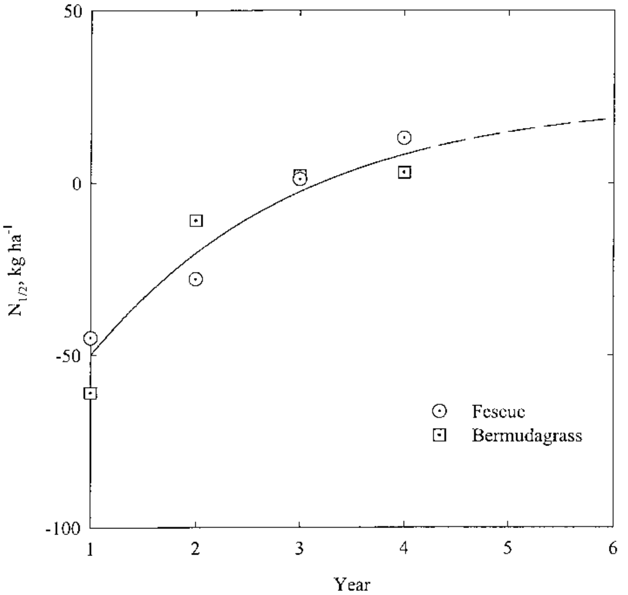

Figure 3. Dependence of model parameter $N_{1/2}$ on year for corn at Watkinsville, Georgia. Data from Table 7. Curve drawn from Eq. (6).

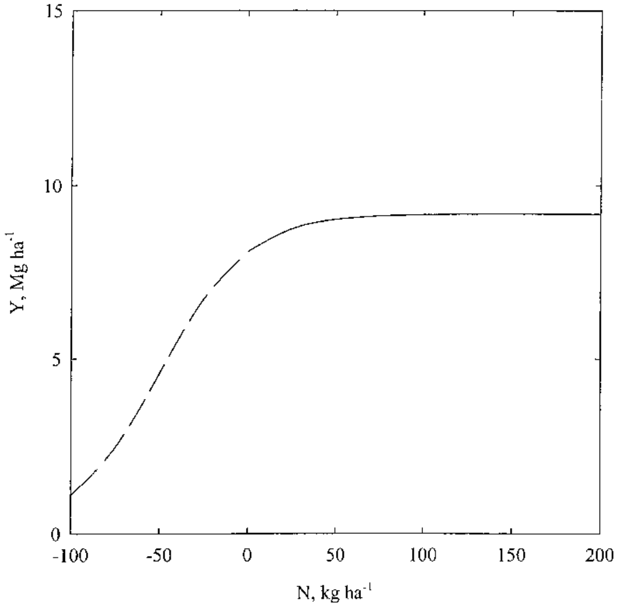

Figure 4. Yield response curve at year 1 after grass sod for corn at Watkinsville, Georgia. Curve drawn from Eq. (8).

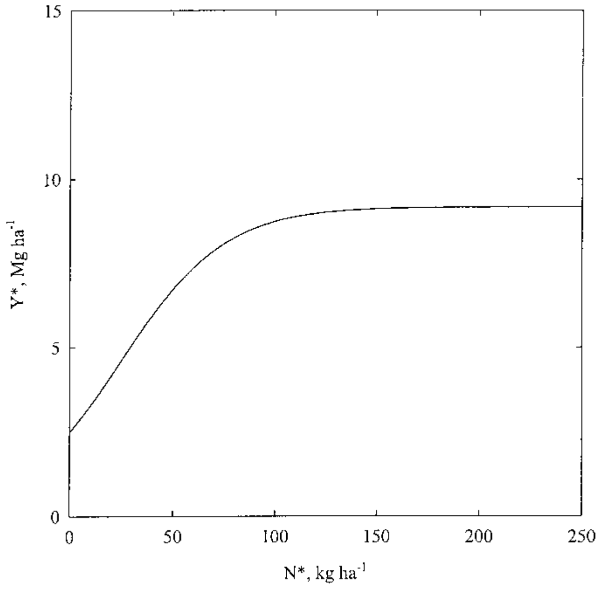

Figure 5. Yield response curve for limiting conditions after grass sod for corn at Watkinsville, Georgia. Curve drawn from Eq. (8).

shifted by $75\,\mathrm{kg\,ha^{-1}}$. These results suggest the linear transformation for the first year

$$N^* = N + 75 \tag{9}$$

which leads immediately to

$$N^*_{1/2} - N^* = 25 - (N + 75) = -50 - N = N_{1/2} - N \tag{10}$$

It follows that the logistic model is *invariant* to the linear transformation [Eq. (9)]. This means that the *form* of the model does not change with changes in residual soil N, and that the variable N can be either positive (added N) or negative (depleted N). This confirms the point made previously by Overman and Scholtz (2002). From this study, as time progressed, residual soil N from the decaying sod was becoming depleted. Yields at $N = 0$ were 88% of maximum for year one and 27% of maximum for the limiting case.

Equation (8) can now be generalized for estimating corn yield by defining effective nitrogen, N^*, as

$$N^* = N + N_e \tag{11}$$

where N_e = extra soil nitrogen from crop residue, which for this case can be estimated from

$$N_e = 75\exp[-0.50(T - 1)] \tag{12}$$

Table 9. Estimates of extra soil nitrogen ($\hat{N}_e$) from decay of grass sod and of corn yield ($\hat{Y}_0{}^*$) at zero applied nitrogen by year (average corn yields are also listed for years 1 through 4 for comparison)

	Year								
Element	1	2	3	4	5	6	7	8	9
$\hat{N}_e$, kg ha^{-1}	75	45	28	17	10	6.2	3.7	2.3	1.4
$\hat{Y}_0{}^*$, Mg ha^{-1}	8.09	6.33	4.87	3.86	3.25	2.94	2.74	2.64	2.57
Y_0, Mg ha^{-1}	8.15	6.25	4.53	3.95	—	—	—	—	—

The time constant for Eq. (12) is 2 years. Estimates of extra soil nitrogen and of corn yield at $N = 0$ are listed in Table 9. Note close agreement between estimated and measured yields. The gradual decomposition of organic matter and release of organic nitrogen by nitrification is apparent in the table. Total nitrogen made available from crop residue is approximately 190 kg ha^{-1}, obtained by summing annual amounts.

DISCUSSION

Several inferences can be made from this analysis. Turning under the sod did release nitrogen for plant uptake by the corn (Figures 1 and 2). The greatest impact was in the first year, with decreasing amounts in subsequent years. Analysis of variance showed that this impact was accounted for in intercept parameter b (Tables 5 and 6), with parameters A and c assumed common over the years. In fact, it appears reasonable to assume $A = 9.18$ Mg ha^{-1} and $N' = 25$ kg ha^{-1} with both fescue and bermudagrass sods. The effect on parameter $N_{1/2}$ appears to be similar for both sods (Figure 3), and values appear to be asymptotically converging toward $N_{1/2} \rightarrow 25$ kg ha^{-1} with time. By the fourth year, this parameter had moved 77% toward the limiting value. It is estimated that the system would move to 95% by year 7. In other words, the effect of residual nitrogen appears for several years.

This article provides further confirmation of the utility of the logistic model for estimating crop response to applied nutrients and management practices. The model should be useful for estimating effect of organic waste (such as animal waste) on crop response to applied nitrogen.

REFERENCES

Adby, P.R. and Dempster, M.A.H. (1974) *Introduction to Optimization Methods*. Wiley: New York.

Carreker, J.R., Wilkinson, S.R., Barnett, A.P., and Box, J.E. (1977) *Soil and Water Management Systems for Sloping Land;* USDA-ARS Publication ARS-S-160. U.S. Government Printing Office: Washington, D.C., 1–76.

Overman, A.R. (1995) Rational basis for the logistic model for forage grasses. *Journal of Plant Nutrition*, 18: 995–1012.

Overman, A.R., Martin, F.G., and Wilkinson, S.R. (1990) A logistic equation for yield response of forage grass to nitrogen. *Communications in Soil Science and Plant Analysis*, 21: 595–609.

Overman, A.R. and Scholtz III, R.V. (2002) *Mathematical Models of Crop Growth and Yield*. Marcel Dekker: New York.

Overman, A.R. and Scholtz III, R.V. (2003) In defense of the extended logistic model of crop production. *Communications in Soil Science and Plant Analysis*, 34: 851–864.

Overman, A.R., Wilkinson, S.R., and Wilson, D.M. (1994) An extended model of forage grass response to applied nitrogen. *Agronomy Journal*, 86: 617–620.

Overman, A.R., Wilson, D.M., and Kamprath, E.J. (1994) Estimation of yield and nitrogen removal by corn. *Agronomy Journal*, 86: 1012–1016.

Reck, W.R. and Overman, A.R. (1996) Estimation of corn response to water and applied nitrogen. *Journal of Plant Nutrition*, 19: 201–214.